Co-products and their role in Life Cycle Analysis of Fuels

Co-product definition

The Low-Carbon Fuel Standard requires the calculation of GHGs generated during the entire pathway from production to use of a fuel. The pathway from feedstock to final fuel production and use involves several processes and operations. These processes have the potential to generate products besides the primary fuel of interest. These additional products are termed co-products.

An example is provided in Table 1 below for various ethanol production pathways which result in a variety of co-products. In general, all fermentation approaches result in solids from spent yeast organisms. In addition, corn ethanol and other starch based crops contain a significant oil and protein fraction. The likely co-products for corn ethanol are shown in Table 1 below.

Table 1. Ethanol Options and Co-Products

Primary Product	Feedstock	Production Location	Co-products
Ethanol, Dry Mill	Corn, Midwest	Midwest	DGS
Ethanol, Wet Mill	Corn, Midwest	Midwest	Corn oil, corn gluten
Ethanol	Sugar Cane, Poplar, Switch Grass, Wood Waste, Forest Residues	Brazil, CA	Fermentation solids, electricity

Table 2 below shows product and co-products for a typical refinery based fuels. Notice that in many instances, co-products themselves tend to be primary products used as transportation fuels.

Table 2. Petroleum Products and Co-products

Primary Product	**Feedstock**	**Production Location**	**Co-products**
CARBOB	Crude Oil	CA refinery	Residual Oil, LPG, Diesel, Kerosene, Coke, Pentanes, Butanes
CARBOB, Imported	Crude Oil	Overseas Refinery	Residual Oil, LPG, Diesel, Kerosene, Coke
CARBOB	Tar Sands, Canada	CA refinery	Residual Oil, LPG, Diesel, Kerosene, Coke, Pentanes, Butanes
CA ULSD	Crude Oil	CA refinery	Residual Oil, LPG, Diesel, Kerosene, Coke
LPG	Crude Oil	CA refinery	Residual Oil, LPG, Diesel, Kerosene, Coke
Natural Gas (CNG, fuel)	Natural Gas	Texas, Canada	LPG
Natural Gas (LNG, fuel)	Natural Gas	Indonesia	LPG
CNG	Landfill Gas	CA	None

Strategies for Co-product Treatment

When a fuel production system produces co-products in addition to the desired product, different methods have been used to attribute emission to co-products. These methods are shown in Table 3 below.

Table 3. Strategies for handling co-products

Strategy	Description
Substitution (or displacement)	Calculate impact of substitute product and assign this value to co-product
Allocation	
Mass balance	Allocate impacts by relative weight of products
Energy basis	Allocate impacts based on relative energy basis of products
Market value	Allocate impacts based on relative market value of products

Displacement Method

The displacement (also alternatively called substitution) method assigns GHG credits to a co-product equivalent to the GHG generated by the production of the product it replaces/displaces from another process. Displacement awards credits against actual impacts for impacts theoretically avoided—an issue that implicates questions of “baseline” and “additionality” familiar to critics of offsets in other contexts. It also leads to circular arguments, where a co-product credit (of, for instance, corn ethanol) is based on the primary product in another system (i.e., soybeans), which is in turn evaluated based partially on the fact that it displaces the first product (i.e., corn).

Most importantly, displacement based on aggregate economic equilibrium analyses is not appropriate for evaluating the co-products of specific products from specific producers. These producers use unique processes to produce co-products with unique characteristics that are sold into specific markets. There may be substantial discretion for choices by fuel producers that affect the real-life impacts of producing and consuming those co-products.

The procedure for using the displacement methods is as follows:

1. The quantity of co-product is determined, measured in most appropriate units for the type of product, expressed per unit of fuel produced. For energy carriers, energy units are preferred, whereas for chemicals, feed, and food products, physical units such as mass or volume are preferred. For example, DGS from ethanol would be expressed in lb of DGS per gallon of ethanol.
2. The life cycle GWI is calculated for the product(s) assumed to be displaced by the co-product in question.

3. An estimate is made of the net displacement of the alternative product. In general, as total supply of the two substitutes increases, substitution will not reach 100% due to supply expansion and price effects. For example, GREET assumes 85% of DDGS substitutes for soybean meal by DDGS, while 15% constitutes new supply.
4. The “co-product credit” is computed, using by the following expression, or the equivalent expression based on energy units rather than mass:

$$Credit = Mass_{coproduct} * \frac{Mass_{substitute}}{Mass_{coproduct}} * \frac{GWI_{substitute}}{Mass_{substitute}} * Displacement\,Factor$$

5. The credit is subtracted from the GWI for the total main production process.

In general, a substitution method is desirable because it accounts for the complete life cycle of the fuel and the co-product. ISO 14040 standard recommends this approach towards co-product credit in life cycle analysis. The analysis is expanded to include the life cycle analysis of the substituted product. Unfortunately, expanding the analysis can introduce additional uncertainty into the life cycle analysis of the original fuel product.

Pros
Most closely related to the environmental impact of the co-product. Potentially takes into account market effects and greater availability of co-products.

Cons
Requires expansion of life cycle analysis to substitute products. In addition, the determination of which substitute product to consider may require an evaluation of several substitute products based on market analysis. The substitute products also require a complete LCA that addresses any co-products. Market effects are more difficult to accurately predict than direct emission effects, especially when new co-products gain large market share (for example corn DGS).

Allocation method

Several methods are used to allocate inputs and emissions within a process to a fuel and co-products. Allocation methods apportion the inputs and emissions from a process based on a characteristic of the process input, outputs, or operation. The advantage of an allocation approach is that the analysis can be completed based on the inputs and emissions associated with a process. No life cycle data is required for substitute co-products (see substitution method), which both simplifies the analysis and eliminates uncertainties due to a more complex analysis. The various types of allocation methods are described below.

a) Mass Balance

The GHG impacts are allocated based on the mass of the output products. The mass balance approach has limited justification because of the weak causality between life cycle energy inputs and emissions and the mass of co-products.

Pros
Often the easiest to compute; a good fall-back position when other methods are deemed to be intractable or too complex.

Cons
Results are often not related to energy inputs and environmental impacts. Energy content (CO_2 potential) of co-products are not always directly related to their masses.

b) Energy Balance

Energy balance may be an appropriate method where all co-products are energy products; because the energy balance associated with a co-product can be viewed as replacing an equivalent product used as an energy source. However, in the case of a mixture of energy and non-energy products such as animal feed, the process energy associated with producing the feed product is not perceived to be closely related to producing the co-product or a substitute. For example, some biofuels processes may require more heat than others to dry fermentable solids such as DGS. The more energy intensive process would assign a greater fraction of the drying energy to the fermentable solids.

Pros
More functionally-based than using mass for energy products.

Cons
Limited in use to energy products. Glosses over quality important differences among energy products (cleanliness, versatility, ease-of-use, depletion effects,

reliance on imports, etc.). Does not reflect the carbon content of different co-products.

c) Market Value

GHG allocations are made based on market value of product and co-product(s).

Pros
Market value is potentially very useful in that it encompasses many of the tradeoffs and substitutability that the displacement method (also) tries to incorporate in an intrinsically responsive, marginal indicator of price.

Cons
Market price volatility can make this an unreliable indicator, and economic externalities, especially in the impacts these methods are used to evaluate, ensure that market prices will not accurately allocate non-market impacts.

Staff recommendations for co-product credit methodologies for several fuel pathways

Primary Fuel	Co-product	Recommended Methodology
CARBOB	Residual oil, LPG, Kerosene, Coke, Pentanes, Butanes	Allocation
ULSD	Residual oil, LPG, Diesel, Kerosene, Coke	Allocation
Natural Gas (CNG)	LPG, CO_2	Allocation
Natural Gas (LNG)	LPG, CO_2	Allocation
Other Fossil	To be evaluated	Allocation
Corn Ethanol (dry milling)	Wet or dry DGS	Displacement
Corn Ethanol (wet milling)	Corn oil, Corn gluten meal and feed	Displacement
Sugarcane Ethanol	Fermentation solids, electricity	Displacement
BioEthanol (biochemical)	Fermentation solids, electricity	Displacement
BioEthanol (thermochemical)	Electricity	Displacement
Soy Biodiesel	Soybean meal, Glycerin	Displacement
Palm Oil Biodiesel	To be evaluated	Displacement
Renewable Diesel	LPG	Displacement
Other biofuels	To be evaluated	Displacement